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THE DISCRIMINATION OF TIME-VALUES IN GEOLOGY.

THE imperfection of the present systems of classification and correlation of sedimentary rocks concerns more directly the interpretation of the facts than the facts themselves.

The work of the geologists of the United States in mapping and recording the stratigraphic sequence of formations was never more exact and comprehensive. The paleontologist was never more particular in his records of the faunal contents of each formation and fossiliferous zone, and his comparisons were never more full and precise. But the extension of knowledge over vast territory has brought to light hundreds and thousands of outcrops of the same formations, showing a diversity of faunal composition which cannot be translated entirely into difference in geologic age.

So long as surveys were confined to local areas separated by spaces across which the continuity of formations could not be traced, it was practicable to use a system of nomenclature and classification in which lithologic formations and their stratigraphic succession were chiefly considered. When, however, the intervals between local areas were filled up and it was necessary to correlate geological sections in which the formational divisions are in part or wholly dissimilar, the duality of the lithologic and biologic facts become apparent. These two sets of facts are entirely different in nature and in origin, and for their scientific discrimination duality of nomenclature is essential.

The confusion of these two kinds of evidence was natural, and has been perpetuated by the common practice of adopting the lithologic formation as the unit of classification, making the time divisions to apply strictly to the formations instead of to the faunas and floras, by which alone the chronologic epochs in which they were formed can be discriminated. This confusion it seen in the discussion of classification and nomenclature in the *Tenth Annual Report* of the United States Geological Survey, and in the legends of the folio maps. For instance, take the Sewanee Folio, Tennessee: The legend is as follows, viz.:

Walden sandstone	Carboniferous.
Lookout sandstone	
Bangor limestone	
Fort Payne chert	
Chattanooga black shale	Devonian.
Rockwood formation	Silurian.
Chickamauga limestone	
Knox dolomite	

According to the rules in the *Tenth Annual Report*, the first series of names are "*structural divisions* . . . . units of cartography, and shall be designated *formations*" (p. 64).

The second series of names are "*time divisions* . . . . defined primarily by paleontology and secondarily by structure, and they shall be called *periods*" (p. 65).

Although everybody understands what is meant by the classification in the legend, the principle described in the rules is wrong in that the legend on the map refers to a classification of rocks: and the real fact in the case is that in the Sewanee quadrangle the Walden, Lookout, Bangor and Fort Payne formations together constitute the Carboniferous *system*, and the map makes no record of periods of time but only of formations of rocks. The Devonian system of that quadrangle consists of the one Chattanooga formation; and the Rockwood, Chickamauga, and Knox formations are the only representatives of the Silurian system recognized on the sheet.

The European nomenclature avoids this confusion by recognizing a set of stratigraphic names and their categories; with a corresponding set of categories for the chronologic classification—the names of the divisions being the same in both the stratigraphic and chronologic scales. Instead of referring all stratigraphic divisions to one category (the formation), different categories are used for formations of different relative size; making the list of names to be group, system, series, stage, as adopted by the international Congress. Each of these stratigraphic divisions has its corresponding chronologic category, viz., era, period, epoch, age. The European has no difficulty in expressing on the map, or in discussing, either the time or the structural relations of the formation. On the map, the Walden, Lookout, Bangor, and Fort Payne would be to him four series, together constituting the Carboniferous system. By placing the Chattanooga in the category of series he at once would indicate that he does not regard the formation as necessarily representing the whole Devonian system. On the other hand, when he speaks of the Carboniferous period he is not discussing any local set of formations but the total period of time in which lived a definite set of plants and animals, only a few of which are discovered in any one local formation. There can be no question that the systems of the European geology can be recognized in this country *only* by the fossils—but that does not change them from formational aggregates into time divisions.

The implication in the *Tenth Annual Report* that the divisions which are discriminated by fossils must be chronologic, and not structural, suggests the way in which our usage may be improved; but the fallacy of the principle is seen by noticing that the smaller formations (the series and ètages of the international nomenclature), are to be discriminated by their fossil contents as well as the larger ones (the systems). If discrimination "primarily by fossils" were to be the test as to whether the division were structural or chronologic then formations would become chronologic divisions in every newly surveyed area in which actual lithologic continuity could not be traced to some standard outcrop.

These two sets of facts (structural and paleontological) both have to do with the classification of formations on a time basis; and those who are accustomed to frame their conceptions of geological time on the basis of one set of facts, find difficulty in even conceiving that there is any other basis.

TIME VALUES OF FORMATIONS.

The regular sequence of stratified sediments forms a natural geological column, which, in any particular section of the earth's crust, is so conspicuously subdivided by lithologic differences in kind of sediments that the divisions form the most satisfactory kind of natural time division for geological classification.

These natural, lithologic divisions of the crust of the earth are technically called formations in the nomenclature of the United States Geological Survey. And in any standard section, such as that of New York state, the order, composition and thickness of the several formations is exactly known; and for that section, too, the fossils of each separate formation are known accurately and in large numbers. Geologists have been accustomed to use such a local column of known geological formations as a *standard time scale;* and as examination has extended to sections of the crust in other parts of the continent, the classification and correlation of the other columns have been made to correspond, by correlation, with such a standard column of formations. Two methods have been used in establishing the correlation: (1) by tracing continuity in the lithologic formation; and (2) by recognition of identity of the fossil species contained in the formations. Both of these methods have rested on an assumed interpretation of the facts, the correctness of which may be questioned quite independently of the established fact of continuity or of identity.

The assumptions on which these interpretations rest are that correlations of time relations can be established in the first case by *continuity of lithologic formation*, and in the second case by *identity of fossils.* In regard to the first case, it would be incorrect to say that the assumption is entirely false, for in some cases, and to a limited extent, lithologic continuity of a formation is undoubtedly synonymous with sameness of the period of the sedimentation represented by the formation. But the facts are abundant, and well known to all field geologists, to prove that formational continuity is not co-ordinate with lithologic uniformity; and since our standard definition of a formation

(*Tenth Annual Report*, United States Geological Survey) is based upon its lithologic uniformity, it is certain that in all cases in which the lithologic changes affect the upper or lower limits of a formation (which is expressed by thinning or thickening of the formation) there must be discordance between the formational continuity and the time represented by it. It requires but a moment's reflection, further, to show that two sections in different regions may, on other evidence, be known to represent the same interval of time but present no similarity lithologically; this can receive only the one interpretation that formational discontinuity does represent time uniformity, which is the converse of the original assumption.

In other words, while it is practicable in some cases to assume that formations which are clearly continuous may be deposited during the same period of time, it is clear that lithologic uniformity (by which the continuity of the formation is recognized) is not a safe guide in making chronologic correlations, however much value may be placed upon the lithologic divisions of a standard geologic section, as natural divisions of a geologic column made on a time basis. The tracing of time equivalences by formational continuity is unsatisfactory, not because of any failure on the part of a formation, as a lithologic unit, to represent a definite period of geologic time, but because the time relations of the formation are not expressed by any of the lithologic characters by which one formation is distinguished from another. The confusion the geologist is apt to fall into in discussing this point may be illustrated by the measurement of the altitude of a rock outcropping on a mountain side. The base of the Olean conglomerate, for instance, as it appears at Olean Rock City may represent exactly the altitude of 2,340 feet above the level of the sea (*McKean County Report, Second Pennsylvania Geological Survey*, R. 59), but its altitude above the sea has no relationship whatever to any of its lithological peculiarities. In forming an altitude scale, it is in the region a conspicuous mark for the altitude at which it lies, and if its dip be considered, the continuity of the conglomerate may be relied upon for estimates of approximate altitude. Nevertheless, in itself the formation possesses no altitude value, it is only a conspicuous stratum in the region where it appears, that now lies at a definite elevation above the sea—the amount of the elevation must be determined by other means. It may indicate an altitude already determined, but it has no intrinsic altitude value, and is not a measure of altitude.

In similar manner we may say that the geologic formation, as a lithologic unit, was formed at some definite epoch of geologic time which may be approximately measured by other means; but the amount of time from any datum point to the time when it was formed is not in any degree indicated by the lithologic or structural characters of the formations; and in this sense a formation may be strictly said to possess no intrinsic time value, but to require the "paleontologic evidence" to prove to what "period" of time it belongs. This conclusion might almost be drawn from the statements regarding periods in the *Tenth Annual Report* (p. 65).

It is, however, not necessary to remind geologists that fossils possess a value as means of determining the time relations of formations. But this time value of fossils will be better appreciated if attention be given to the nature of the evidence furnished by fossils regarding the period of time in which they lived.

TIME VALUE OF FOSSILS.

Fossils derive their time-value from the fact that the morphologic characters presented by them are temporary in nature. The form of a trilobite, expressed in its various morphologic characters, was constructed by organisms at a definite period of time in the history of the earth; so that the presence of a fossil trilobite imbedded in a rock formation is direct evidence of the geologic age in which alone the trilobite lived. Hence it is that for the whole surface of the earth fossils become marks of the time divisions and the means of correlating formations on a time-basis; this is the second method of correlation referred to above. Identity of fossils is direct evidence of sameness of time. But in applying such a statement much confusion and imperfect correlation has arisen by failure to recognize *wherein consists* the time-value of the fossil.

Identity of fossils may be wrongly interpreted—a trilobite is a trilobite, it is true, but one trilobite is a *Paradoxides* and another is *Phacops;* and the one indicates an early period of Paleozoic time, while the latter indicates a much later period. Then, again, *Phacops cristata* appeared in the early part of the life history of the genus *Phacops*, while *Phacops rana* is a later species of the same genus. Thus it is evident that in speaking of *identity* of fossils one may have in mind the same *class*, the same *order*, or the same *family*, *genus*, or *species;* and the time value will differ according to the category of zoölogical classification to which the identity applies. The time represented by the morphological character of the genus *Paradoxides* is much shorter in length than that represented by the sub-class Trilobita; and the period of time represented by the characters of the genus *Paradoxides* is diverse from that represented by the genus *Phacops*. So in regard to all kinds of organisms represented by fossils: the morphological characters expressive of the more comprehensive zoölogical divisions are of greater antiquity than those of less comprehensive divisions. The time-value of a class character is, in most cases, as long as all the recorded time of stratified rocks; while the time-value of a species is often not over a tenth of that length.

In order to discuss these time relations it becomes necessary to make scientific discrimination of the characters of organisms in their time relations. First of all, what is it about the organism which is directly co-ordinate with time? An answer to this question will be reached by considering the fundamental characteristic of organisms—their *growth*. The form possessed by any organism living is expressed only as the individual grows or develops from an embryonic or *formless* state. The form is *acquired* by each individual organism; always by individual development requiring duration of time. This time is the living period of the individual. If every individual developed some morphologic peculiarity by which it could be distinguished, each such individual would represent a definite point of time, and the succession of individuals thus distinguished would express the history of the world in terms of the life periods of the successive individuals. Practically it is impossible so to distinguish the characters of individuals that they can serve as time indicators.

The naturalist does, however, recognize characters of sufficient distinctness to differentiate one species from another. Specific characters, like individual characters, have been acquired gradually as generation has succeeded generation in ordinary reproduction. The process of acquiring specific characters is called evolution; and specific evolution takes longer time than individual development. The length of time during which in any particular race generation continues without appreciable disturbance of the specific characters of the offspring, varies in different lines of descent, and specific characters are more readily distinguished in one case than in another. But in all cases the continuity of the specific characters without special change represents a considerable period of geological time, and this length of time is measured by the presence in the formations of the same species of fossils. The period of the continuance of the same species is therefore a definite length of time for each species, since each species began at some definite time, and (unless now living) became extinct at a later definite point of time. This definiteness of the life-period of a species is independent of our present knowledge either of its measure in years, or of the thickness or stratigraphic position of the formation in which the fossils are preserved.

Having noted that the morphologic characters of organisms are temporary in nature, we may further observe that this temporary quality has to do with the vitality of the organism in a measurable way. As in the case of two living organisms we consider the vigor of that one to be the greater, which, under similar circumstances, lives the longer; so, in general, the length of endurance of a species may be taken as the measure of some kind of enduring power which inheres in the race itself. This enduring power of organisms, expressed by the repetition of like characters in successive fossil forms, is the time quality which has already been used by geologists in making correlation of formations by fossils, and to which we must look for the making of a scientific time-scale.

In order to isolate this time quality I have proposed to speak of it as the *bionic* quality or value of the organism. *The bionic quality of an organism may, then, be defined as its quality of continuing, and repeating in successive generations, the same morphologic characters.* In the case of the unit individual, it is the *continuing* of the characters, since biologically the use of parts wastes them; and only as they are renovated· may they be said to continue; the active organs are here alone under consideration, for the inactive hard parts are biologically dead parts whose endurance is dependent only on absence of agencies of destruction. If, now, we can discover some way of observing, recording, and measuring the bionic values of fossils, we will be furnished with a means of constructing a geological time-scale on a separate (not to say independent) basis from the supposed time-scale represented by the geologic column of successive formations.

In the development of such a time-scale the first point to notice is that *the characters of organisms differ in their bionic value in direct proportion to their taxonomic rank.* Thus, as we have seen in the case of the Trilobites, the characters which have ordinal or sub-class rank have persisted in the history of organisms vastly longer than the characters of generic value; and these are of greater bionic value than specific characters.

In discriminating periods in geological time we may look first to the well-known categories of zoölogy and botany, as a basis of determination of the order of rank in the time divisions, viz., the time of endurance of a specific character (or, concretely, the length of time represented by the presence of the same species in successive strata of the rocks) is of subordinate rank to the time of endurance of a generic character. And if we should adopt the name *chron* to apply to geological time-units in general, and *biochron* to the units whose measure is the endurance of organic characters, we have a means of constructing a system of nomenclature which will express what is now known of geological time relations, and (more important still), which will serve as an aid in accumulating the necessary statistics to perfect the geological time-scale.

ORDER OF MAGNITUDE OF BIONIC UNITS.

In expanding this system of nomenclature the following table will indicate the principle upon which the fundamental units of time value will be discriminated and named. The time unit of lowest rank will be based upon the life endurance of an individual organism; the amount of organic vigor expressed by the preservation of the individual life constitutes a bionic unit of simplest or lowest rank; the individual, therefore, is an organic unit of monobionic rank. How many individual lives are possible in the life-history of a species we at present do not know, but we do know that the bionic value of the species (or, strictly speaking, of specific characters) is of an entirely higher order than that of the individual. To be more concrete the individual, the species, the genus, etc., constitute organic units of consecutively higher and higher order of bionic magnitude, which statement may be tabulated in the following way:

THE BIONIC VALUES OF THE SEVERAL CATEGORIES OF CLASSIFICATION OF ORGANISMS.

Individual - -	a monobionic unit.
Species - -	a diobionic unit.
Genus - -	a tribionic unit.
Family - -	a tetrabionic unit,
Order - -	a pentabionic unit.
Class - -	a sexbionic unit.

In the table the bionic order of magnitude is expressed by the prefix *mono-*, *di-*, *tri-*, etc.; thus the dibionic unit is an abstract mode of naming the order of magnitude of the organic force expressed in preserving, by generation, the specific characters of an organism. Comparing this with the force which preserves in like manner generic characters, the former is seen to be of second order of magnitude, while the latter is of tertiary order of magnitude. So far the magnitudes are relative, and they become concrete only when the bionic value of the characters of some particular species or genus is considered.

Paleontologists are familiar with the very long range of the species *Atrypa reticularis; Rhynchonella cuboides*, on the other hand, has a very short range. In the nomenclature proposed (so long as both are considered to be species), the fact would be expressed by saying that the *Atrypa reticularis* biochron is longer than the *Rhynchonella cuboides* biochron. Nevertheless, in the familiar categories used by the zoölogist and botanist is found a means of expressing definiteness in, at least, the order of magnitude of biochrons; whereas there is no way of distinguishing the order of magnitude of geochrons, except in feet thickness. In the case of the biochron it is only necessary to indicate the name of the species or genus in order to fix a definite value to the biochron. Such values are already definitely expressed when we speak of the "reptilian age," the "age of fishes," the "olenellus zone." The definiteness is indicated by the name of the particular group of organisms made use of, or adopted as the measure of the biochron.

THE DUAL NOMENCLATURE.

In proposing a dual nomenclature it is essential to indicate this basis of measurement of the chron, and to distinguish the *geochron* (expressed in terms of feet thickness of stratified sediments of uniform lithologic constitution) from the *biochron* (expressed in terms of presence in the sediments of fossils of the same species, genus, or family).

Thus the time value of the Hamilton formation would be spoken of as the *Hamilton geochron;* while the time value of the species *Tropidoleptus carinatus* would be the *Tropidoleptus biochron.* The same kind of difference in values is observed to pertain to both biochrons and geochrons. As it is impossible to fix any standard length for the endurance of a species, so it is impossible to fix any standard of thickness for geological formations; they may vary from a few inches to many hundreds of feet in thickness.

Since the thickness, as well as the kind of sediment, varies with the geographical locality, the association of a geographical name with the lithologic character of the formation becomes a definite and precise mode of identifying a formation; so that the name "Medina sandstone" becomes a definite formation name, the characteristics of which may be observed, and their definition fully elaborated at Medina, where the formation appears with its typical characters. Its place in a geological column, its thickness, and its composition, are all made definite by the name *Medina;* any sandstone outcropping elsewhere can be classed as "Medina sandstone" only by possessing the characters considered to be essential to formational continuity and integrity. Of course one of those characters may be theoretically defined as the geologic time of its deposition; this may be indicated by the contained fossils. But formational continuity and identity may be established in the case of non-identity of fossils, and in one section the fossils may rise to a higher stratigraphic plane than in another; so that actual *formational continuity may disagree with the evidence of duration presented by the fossil species.* This fact is illustrated in the case of the Catskill formation, which is known to occupy a stratigraphic position in eastern New York and Pennsylvania continuous with rocks further west, possessing both different lithologic characters and containing fossils regarded as characteristic of the Chemung formation. Such facts find easy expression when the nomenclature is furnished us by which to separate a geochron from a biochron. The *Spirifer disjunctus* biochron is a different thing from the Chemung geochron. In defining the Chemung formation it has become necessary to distinguish it from the formation following it. This following formation in many sections in New York and Pennsylvania is a red sandstone and shale lacking the marine fossils, sometimes holding fish of possibly marine, but probably brackish-water habitat. For purposes of mapping and classification, the Chemung formation is succeeded by the Catskill formation; but the evidence is conclusive that the time of deposition of the red sediments of the Catskill formation of eastern

New York was in large measure synchronous with the sedimentation of gray rocks with abundant marine fossils, including *Spirifer disjunctus*, in western New York and Pennsylvania.

If the endurance of the *Spirifer disjunctus* fauna be made the mark of the *Spirifer disjunctus* biochron, it becomes quite possible to state and discuss the facts as they are, and to understand the natural explanation of the facts as a gradual transgression of the shore from which the red sediments were deposited westward with the progress of time. The geochron of red beds began earlier in the scale of biochrons, and as we expand the idea we will discover that it is also earlier in actual geological time, and that the biochron is the measure upon which we must depend in constructing the standard geological time-scale.

THE CONSTRUCTION OF A BIONIC TIME SCALE.

The next question arises, how shall this time-scale be constructed? First, it must be constructed, primarily, on the basis of the bionic values of the fossils. Secondly, the names of the time divisions must be distinct from those used in designating the formational divisions of the rocks. Thirdly, biological names should be chosen for the divisions, and so far as practicable, some abundant or characteristic fossil should furnish the name; as in naming formations the locality in which the formation appears in full force and with full characteristics is used. Fourthly, it cannot be expected that the divisions of an accurate time-scale, based upon many different sources of measurement of the time intervals, will present a continuous series without breaks and without overlapping of the divisions. If a single means of measuring the lapse of time were used, such breaks and lapping might be avoided; only in case the beginning of one species or fauna was everywhere dependent upon the cessation of the preceding one, could the scale be made without liability of failure to meet at the limits of the time intervals indicated. Fifthly, the classification and definition of geological formations should be made, so far as practicable, independent of the fossils or the time relations indicated by them; and the fossils should be used (as now their use is scientifically most valuable) in establishing correlations, not in furnishing definitions. Sixthly, the selection of the grander time divisions should be made to conform, so far as found practicable, with the standard divisions of the formation scale; but their discrimination should be based strictly upon fossil evidence and not upon the lithologic or stratigraphic characters of formations. Seventhly, in forming the time-scale the continuance of the fauna in its integrity, as marked by the dominance of its characteristic species, will constitute a more satisfactory basis of discrimination than the species alone. Slight differences in the aggregate of species found in the successive strata of rocks is quite consistent with the continuance of the fauna in its integrity, and to distinguish the *fauna* as a whole from its local and temporary expression the latter may appropriately be called a *faunule*.

In constructing a time-scale on the basis of the bionic values of fossils, it is practicable to give to the categories now in use greater precision and scientific definition. If geologists chose to adopt the following terms in the restricted sense designated, such a set of terms would prove of great value.

TERMS OF THE BIONIC TIME SCALE.

Chron.—An indefinite division of geological time.

Geochron.—The time equivalent of a formation.

Biochron.—The time equivalent of a fauna or flora.

Hemera.—The technical name for a monobiochron, indicated by the preservation of the individual characteristics of all the species of a local faunule, as shown by the association in the rocks of the same species, in the same relative abundance, size, and vigor. An example is the hemera of *Rhynchonella* (*Hypothyris*) *cuboides*.

Epoch.—The name of a dibiochron, indicating the time equivalent of the endurance of a particular species and of the integrity of the fauna of which it is the dominant characteristic. An example is the *Tropidoleptus carinatus* epoch, which corresponds closely to the limits of the Hamilton formation of eastern New York.

Period.— May be defined as a tribiochron. This is the time equivalent of the continuance of a *genus*. An example is the *Paradoxides period*, which corresponds to the Acadian formation of the Cambrian system.

Era.—May be used to indicate a tetrabiochron; and *Olenide era* would indicate the life range of the family *Olenidae*, corresponding in length, approximately, to the geochron of the Cambrian system, though not strictly so.

Eon.—May stand as the name for a pentabiochron; an example of which is the *Trilobite eon*, the time equivalent of the continuance of the order, or sub-class, *Trilobita*, which closely approximates the length of the Paleozoic geochron.

CLASSIFICATION AND NOMENCLATURE OF THE TRILOBITE EON (PALEOZOIC) CONSTRUCTED ON THE BASIS OF THE BIONIC VALUES OF FOSSILS.

Eon	Periods	Epochs	Formational Equivalents (Approximate)
Trilobiteon	7. Phillipsian	Cameratus	Coal measures.
		Increbescens	Kaskaskia, St. Louis.
		Logani	Keokuk, Burlington.
		Marionensis	Kinderhook.
	6. Phacopsian	Disjunctus	Chemung.
		Mucronatus	Hamilton.
		Acuminatus	Corniferous.
		Arenosus	Oriskany.
		Macropleurus	Lower Helderberg.
	5. Calymenean	Vanuxemi	Waterlime, etc.
		Radiatus	Niagara, etc.
	4. Asaphian	?	Ordovician.
	3. Olenian	?	Cambrian.
	2. Paradoxidean		
	1. Olenellian		

Applying the principles set forth in this paper, a tentative table may be constructed which will express concretely what is meant by a biochronic classification and nomenclature. In this table the attempt is made to find names of genera of Trilobites for the periods of that eon in which Trilobites constitute a characteristic feature. The genera chosen actually do lap over each other in several places, but it is doubtful if any genera could be chosen which, if they did not lap over in their chronologic range, would leave actual gaps not represented in any division of the scale. The genus *Spirifer* is selected in the upper divisions of the scale, as furnishing a convenient set of diagnostic species; they, too, do not in every case avoid lapping, a difficulty which it has already been said is unavoidable when the means of measurement are multiple and not mutually exclusive. The foregoing table is offered, then, as a means of illustrating the proposed plan.

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